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P-WAVE CHARM MESONS AS A WINDOW TO THE D_{sJ} STATES*

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In my talk I discussed the properties of the newly discovered $D_{sJ}^*(2317)$, $D_{sJ}(2460)$, $X(3872)$, and SELEX $D_{sJ}^*(2632)$ states and suggested experimental measurements that can shed light on them. In this writeup I concentrate on an important facet of understanding the D_{sJ} states, the properties of the closely related D_0^* and D_1' states. These states are well described as the broad, $j = 1/2$ non-strange charmed P-wave mesons.

Keywords: Charm Mesons; Charm-strange mesons; quark model.

1. Introduction

The last sixteen months has seen the discovery of the $D_{sJ}^*(2317)$[1], $D_{sJ}(2460)$[2], $X(3872)$[3], and $D_{sj}(2632)$[4] states. All of these states have properties significantly different from what was predicted beforehand for conventional $q\bar{q}$ states. This has led to considerable theoretical speculation that these states may be something new such as multiquark states or meson-molecules. Another point of view is that conventional $q\bar{q}$ explanations cannot yet be ruled out and there are diagnostic tests that should be applied to understand the nature of these newly discovered states. In my talk I discussed the $q\bar{q}$ possibilities for these new states and the quark model predictions that can be used to test them. Due to length restrictions I will restrict this writeup to new results on the D_0^*, D_1', and D_{sJ} states and refer the interested reader to published work on the $X(3872)$[5] and SELEX $D_{sJ}^+(2632)$[6] states.

2. The D_{sJ} States and Their Nonstrange Partners

The four $L = 1$ P-wave mesons can be grouped into two doublets characterized by the angular momentum of the light quark: $j = 3/2$, $1/2$. The $j = 3/2$ $c\bar{s}$ states were predicted to be relatively narrow and are identified with the $D_{s1}(2536)$ and $D_{s2}(2573)$ states while the D_{s0}^* and D_{s1}' $j = 1/2$ states were expected to have large S-wave widths decaying to DK and D^*K respectively[7]. Quite unexpectedly the Babar[1] and CLEO[2] collaborations discovered two charm-strange mesons in B-decay, decaying to $D_s^+\pi^0$ and $D_s^{*+}\pi^0$ which were below the DK and D^*K threshold respectively. Virtually all the theoretical effort has concentrated on these states [8].

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However, their nonstrange partners can also hold important clues to the puzzle but have received almost no attention.

The measured properties of the $L = 1$ charmed mesons are summarized in Table 1 along with quark model predictions[7,9,10]. The quark model gives a P-wave cog that is ~ 40 MeV too high but the splittings are in very good agreement with the measured masses. The width predictions are given for the pseudoscalar emission model with the flux-tube model giving qualitatively similar results[7]. We note that Belle[11] and FOCUS[12] measure $\Gamma(D_2^{*0}) = 37 \pm 4.0$ MeV and $\Gamma(D_1^0) = 23.7 \pm 4.8$ MeV which are slightly larger than the PDG values. They attribute the difference from older results to taking into account interference with the broader D states. Overall the agreement between theory and experiment is quite good.

Table 1. Comparison of Quark Model Predictions[7,9,10] to Experiment for the L=1 Charm Mesons.

State	Mass (MeV)		Width (MeV)	
	Theory[a]	Expt	Theory[b,7,10]	Expt
D_2^*	2460	2459 ± 2 [c]	54	23 ± 5 [c]
D_1	2418	2422 ± 1.8 [c]	24	$18.9^{+4.6}_{-3.5}$ [c]
D_1'	2428	2438 ± 30 [d]	250	329 ± 84 [d]
D_0^*	2357	2369 ± 22 [e]	280	274 ± 32 [e]

[a] The P-wave cog[7,9] was adjusted down 42 MeV.
[b] Using the masses from column 2.
[c] Particle Data Group[13]
[d] Average of the Belle[11] and CLEO[14] $D_1'^0$ measurements
[e] Average of the Belle[11] D_0^{*0} and FOCUS[12] D_0^{*0} and D_0^{*+} measurements.

Radiative transitions probe the internal structure of hadrons[15,16,17]. Table 2 gives the quark model predictions for E1 radiative transitions between the $1P$ and $1S$ charm mesons[10]. Some of these transitions should be observable. The $D_1^0 \to D^{*0}\gamma$ and $D_1^0 \to D^0\gamma$ transitions are of particular interest since the ratio of these partial widths are a measure of the $^3P_1 -^1 P_1$ mixing angle in the charm meson sector and a good test of how well the HQL is satisfied.

The overall conclusion is that the quark model describes the P-wave charmed mesons quite well and models invoked to describe the $D_{sJ}^*(2317)$ and $D_{sJ}(2460)$ states must also explain their non-strange charmed meson partners.

Turning to the D_{sJ} states, the narrow $j = 3/2$ states are identified with the $D_{s1}(2536)$ and $D_{s2}(2573)$ with their observed properties in good agreement with quark model predictions[7,9]. The $j = 1/2$ states were predicted to be broad and to decay to DK and D^*K and were not previously observed. But the $D_{sJ}^*(2317)$ is below DK threshold and the $D_{sJ}(2460)$ is below D^*K threshold so the only allowed strong decay is $D_{sJ}^{(*)} \to D_s^{(*)}\pi^0$ which violates isospin and is expected to have a small width[15,16,17]. As a consequence, the radiative transitions are expected to have large BR's and are an important diagnostic probe to understand the nature

Table 2. Partial widths and branching ratios for E1 transitions between $1P$ and $1S$ charmed mesons. The widths are given in keV unless otherwise noted. The M_i and the total widths used to calculate the BR's are taken from Table 1. The matrix elements are calculated using the wavefunctions of Ref. 9.

Initial state	Final state	M_i (GeV)	M_f (GeV)	k (MeV)	$\langle 1P\|r\|nS\rangle$ (GeV^{-1})	Width (keV)	BR
D_2^{*+}	$D^{*+}\gamma$	2.459	2.010	408	2.367	57	0.25%
D_2^{*0}	$D^{*0}\gamma$	2.459	2.007	411	2.367	559	2.4%
D_1^{+}	$D^{*+}\gamma$	2.422	2.010	377	2.367	8.8	5×10^{-4}
	$D^{+}\gamma$	2.422	1.869	490	2.028	58	0.3%
D_1^{0}	$D^{*0}\gamma$	2.422	2.007	380	2.367	87	0.5%
	$D^{0}\gamma$	2.422	1.865	493	2.028	571	3.0%
$D_1'^{+}$	$D^{*+}\gamma$	2.428	2.010	382	2.367	37	10^{-4}
	$D^{+}\gamma$	2.428	1.869	494	2.028	15	4×10^{-5}
$D_1'^{0}$	$D^{*0}\gamma$	2.428	2.007	385	2.367	369	0.1%
	$D^{0}\gamma$	2.428	1.865	498	2.028	144	4×10^{-4}
D_0^{*+}	$D^{*+}\gamma$	2.357	2.010	321	2.345	27	10^{-4}
D_0^{*0}	$D^{*0}\gamma$	2.357	2.007	324	2.345	270	0.1%

of these states[15,16,17]. Although there are discrepancies between the quark model predictions and existing measurements they can be accomodated by the uncertainty in theoretical estimates of $\Gamma(D_{sJ}^{(*)} \to D_s^{(*)}\pi^0)$ and by adjusting the ${}^3P_1 -{}^1P_1$ mixing angle for the D_{s1} states. As in the case of the D_1 states, the radiative transitions to D_s and D_s^* can be used to constrain the ${}^3P_1 -{}^1P_1$ $(c\bar{s})$ mixing angle.

The problem with the newly found D_{sJ} states are the mass predictions. Once the masses are fixed the narrow widths follow. My view is that the strong coupling to DK (and D^*K) is the key to solving this puzzle.

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